

# Berkeley Lab DER Seminar Series Winter 2002

*Conference Room 90-3148, 12-1 unless otherwise noted*

	date	speaker	title
1	Tue, 3 Dec.	<i>Chris Marnay</i>	Introduction to Distributed Generation and the CERTS Microgrid
2	Thu, 5 Dec.	<i>Francis Rubinstein</i>	An Embedded Device Network for Lighting and Building Equipment Control
3	Tue, 10 Dec.	<i>David Littlejohn</i>	The Role of Combustion Research in Developing Quality DER Systems
4	Thu, 12 Dec.	<i>Tim Lipman</i> , CIDER	Vehicles as Mobile Sources of Generation and Ancillary Services
5	Tue, 17 Dec. (Room 90-3075 @ 12:30pm)	<i>Dimitri Curtil</i>	DER Simulation by Linking SPARK with EnergyPlus
6	Thu, 19 Dec.	<i>Hugh Outhred</i> , U. of N.S.W., Australia	An Australian Perspective on DER

*presentations will be posted at [der.lbl.gov](http://der.lbl.gov)*

# THE ROLE OF COMBUSTION RESEARCH IN DEVELOPING QUALITY DER SYSTEMS

December 10, 2002

Presented to Berkeley Lab DER Seminar Series

by

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Carlo Castaldini is a consultant to utilities and industry on process efficiency and emission controls

# AGENDA

- Dave:
  - Combustion, DER, Emissions, and Efficiency
- Carlo:
  - DER makes sense in many cases if it meets vital economic and environmental tests
  - Lots of different DER technologies and system integration opportunities
  - Best opportunities rely on implementation of “quality” DER, often based on efficient waste heat utilization
- Dave:
  - Alternative Fuels, Biofuels, Hydrogen

# Combustion and DER

- Combustion is responsible for 85% of US's energy supply and is expect to remain dominant in the foreseeable future
- Therefore, combustion is integral to most DER systems:

	Combustion relevancy	Cost	Emissions
• Microturbines	***	med	low
• Reciprocating Engines	***	low	very high
• Fuel Cells	*	very high	very low
• Hybrids	**	high	low
• Photovoltaics	-	high	none
• Wind	-	med	none

# DER for Industrial Processing

- Manufacturing
  - Petroleum and chemical processing
  - Food processing
  - Biotech and drugs
  - Electronics
  - Building construction materials
- Industrial Buildings & Campuses
  - buildings for offices, research, and manufacturing

# Optimizing Efficiency and Emissions for DER

- Now is the time to determine the efficiency and emissions parameters that are acceptable for industrial and manufacturing DER systems
  - Use **CHP** whenever possible
    - Manufacturing requires a large amount of heat
    - Take full advantage of high combustion efficiency for heating (close to 100%)
    - Minimize emissions of CO<sub>2</sub> per unit of energy produced
  - **Goal:** achieve efficiency and emissions as good or better than modern combined cycle power plant > 60%
  - **Approach:** Equal emphasis on electrical and heat needs
    - Very often site's heat needs are relegated to secondary importance
    - Tailor the DER system to the site's energy needs:
      - how much electricity?
      - how much high pressure steam?
      - how much low pressure steam?
      - how much hot water?

# Background on Emissions Reporting

- NOx emissions - oxygen concentration in the exhaust is an important parameter when evaluating and reporting emission levels
- Boilers and furnaces are generally referenced to 3% oxygen (boilers and furnace run close to stoichiometry)
- Turbines and microturbines are generally referenced to 15% oxygen (turbines require addition of bypass air to protect blades from excessively high temperatures)
- e.g. correction to 3% O<sub>2</sub>  
$$\text{NOx ppm ( @3\% )} = [21 - 3 / 21 - \text{O}_2 \text{ (actual)}] \times \text{ppm (actual)}$$
- An alternative unit for assessing emissions is pounds/MMBtu (or equivalent SI units) - this eliminates the issue of dilution. Divide by the system efficiency to obtain NOx per unit of useful energy produced.

# BENEFITS OF DER

- Transition to competitive energy marketplace underway
- Grid independence (Reliability/Security/Control)
- Diverse set of DER technologies emerging
- Power generation closer to end use
- Greater fuel efficiency for quality systems
- Streamlined permitting process
- Environmentally clean technologies
- Can provide ancillary services



# TYPES OF DER

- Commercial Prime Movers:
  - GT (MTG) w/or w/o recuperator (30 kW to 20 MW)
  - Recips (spark-ignited or diesel, 5 kW to 5 MW)
- Commercial Bottom Cycle
- Commercial Renewables:
  - Wind, PV, Biofuels (>5 kW)
- Demonstration Stage
  - Fuel cells (5 to 1,000 kW)
- Long-Term Development
  - Stirling engine
  - FC-Hybrids

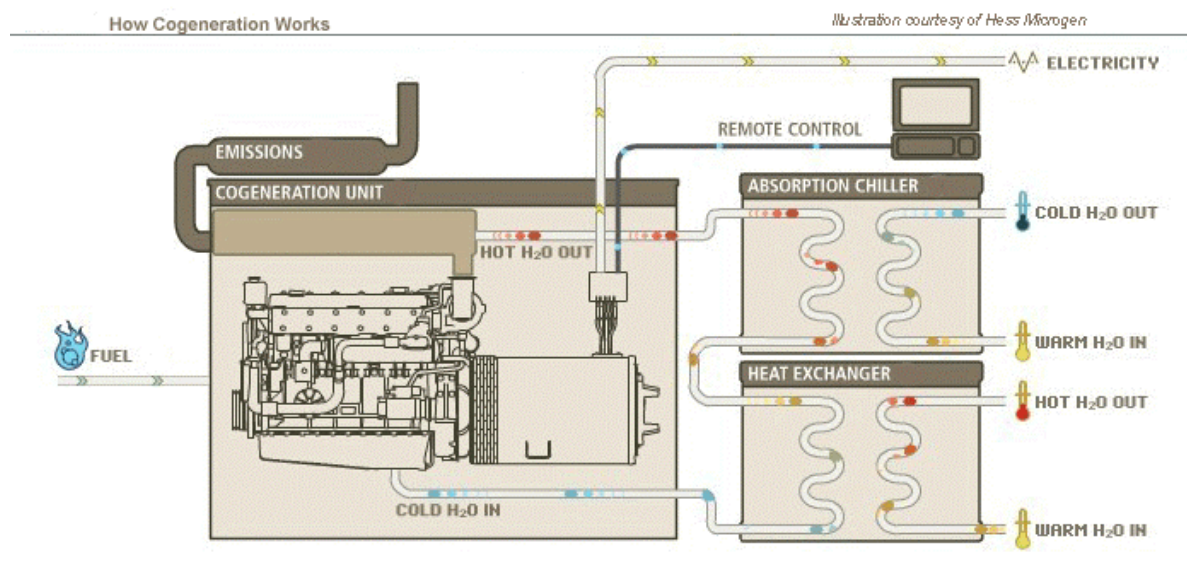
# ENERGY AND EMISSIONS

## FUNDAMENTALS OF DER-CHP

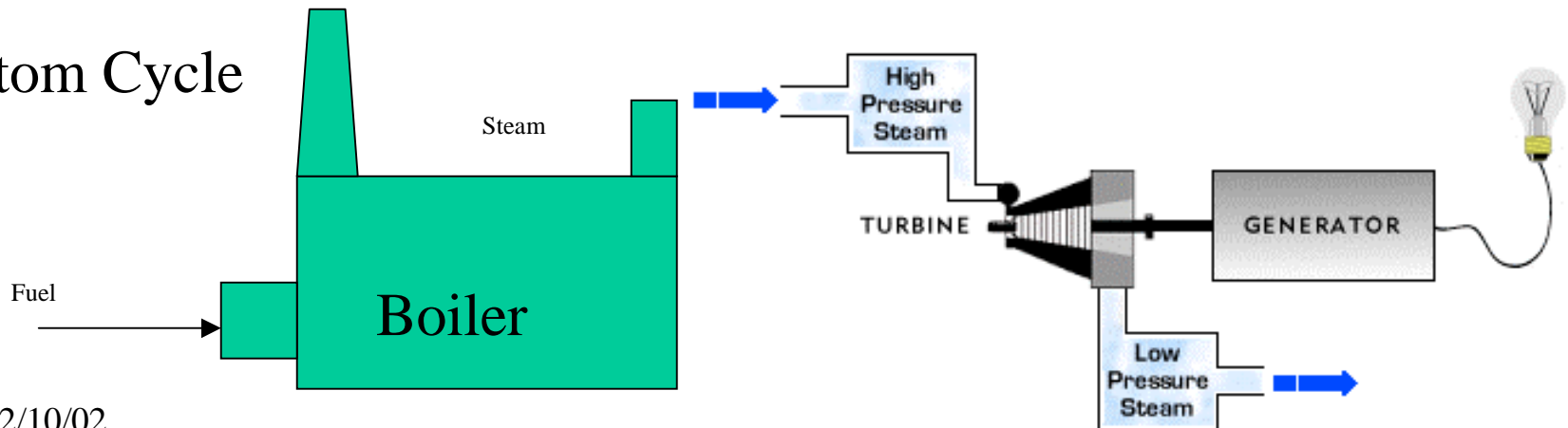
- Brayton/Otto Cycle: 1 Unit Fuel Energy input  $\Rightarrow$  0.33 total energy output (work) [A/F=30/1-50/1 – Lots of extra air and high Texit]
- Process Heat: 1 Unit Fuel Energy Input  $\Rightarrow$  0.75 Units output (thermal) [A/F =12/1 Near stoichiometry, low Texit]
- CHP = Brayton/Otto [Prime Mover] +(Rankine)+ Steam : 1 Unit Fuel Energy input = 0.60 to 0.85 total energy (work+thermal)
- NOx emissions from natural gas fired equipment:
  - Recips = 0.5 to 2.0 lb/MMBtu [2.0-8 g/bhp-h] (rich and lean engines)
  - MTG = 0.03 to 0.07 lb/MMBtu (with 15-18% O<sub>2</sub> in exhaust gas)
  - Boilers = 0.01 to 0.04 lb/MMBtu (with 3% O<sub>2</sub> in flue gas)
- Rich-burn recips. gaining in popularity over MTG because of cost/efficiency. However, require 3-way catalysts

# TWO MAIN WAYS TO GENERATE ONSITE

## Prime Mover



## Bottom Cycle



12/10/02

# INSTALLED DER CAPACITY

- 34-75 GW TOTAL CAPACITY
- MOSTLY IN 0.3 TO 1 MW RANGE
- MOSTLY INDUSTRIAL COGEN
- DISTRICT HEATING (esp. Europe)
- CAPACITY GOALS:
  - US DOE : UP TO 18% BY 2010
  - Europe: Similar targets
  - Some European Countries: up to 77%

# MARKET CHALLENGES

- Meet increased customer load
- Grid connect standardization
- Asset capitalization
- Interconnect fees (Stakeholders)
- Operation and maintenance
- Grid backup
- Secure fuel supply and cost
- ROI typically greater than 2 yrs

# MARKET PROMOTERS

- State backed low interest loans
- Generous tax credits
- Major advances in reliable technologies
- Emergence of OEMs and O/O Business Entities
- Potential for reduced capital cost
- Potential for significant energy savings
- Promise for low emissions (FC)

# DER MYTHS

- DER WILL REPLACE CENTRAL STATION GENERATION
- LOTS OF MONEY CAN BE MADE IN DER
- DER CAN BE INSTALLED FOR LESS THAN \$500/kW
- RESIDENTIAL/SMALL COMMERCIAL REPRESENT GREATEST POTENTIAL FOR DER

# QUALITY DER/DG

- Comparison with central CC plant:
  - Greater efficiency
  - Lower power generation cost
  - Lower emissions
  - Equal or greater availability/reliability
  - Modularity/staged deployment
  - Low maintenance
  - Siting options (Customer/Substation)
  - More cost effective than T&D upgrade
  - ROI less than 2 years

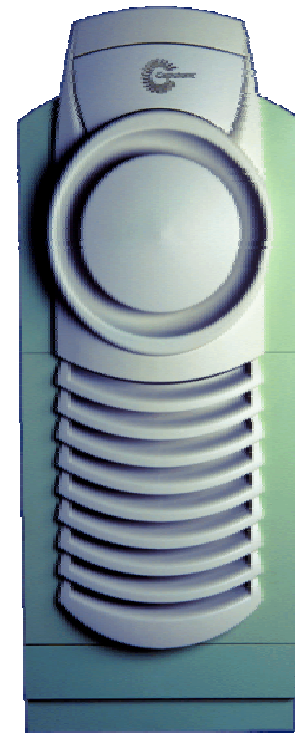


# GT-CHP QUALITY DER

- Simple cycle DER with GT or RICE is NOT Quality DG
- Types of Quality CHP:
  - MTG with passive sensible heat recovery (lower efficiency)
  - MTG with supplemental combustion air heat recovery (higher efficiency with exhaust temperature boost)

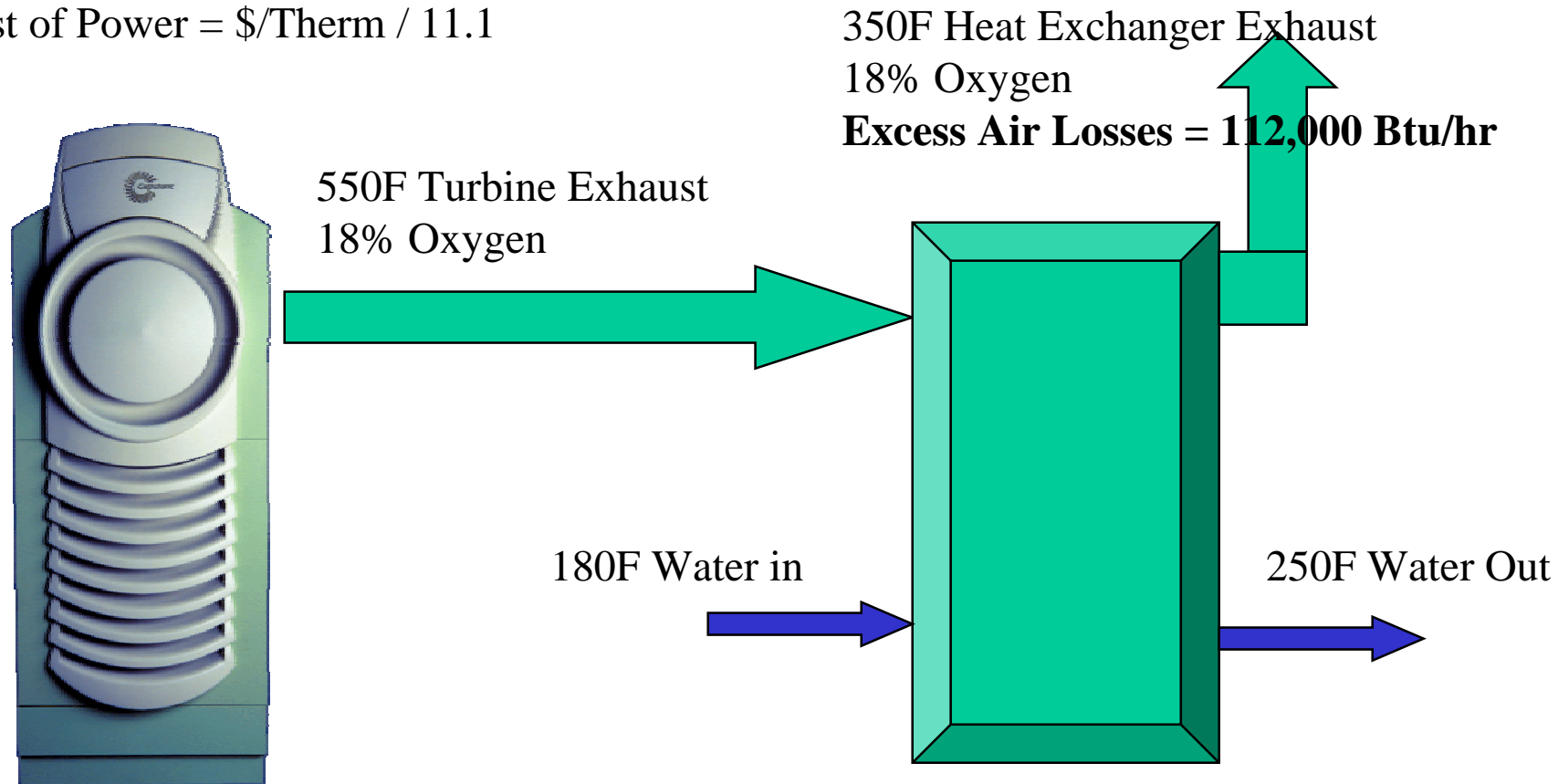
# HEAT RATE WITHOUT RECOVERY

- 14570 Btu/kW-hr HHV
- Cost of Power = \$/Therm / 6.9



# HEAT RATE WITH SENSIBLE HEAT RECOVERY

- 9032 Btu/kW-hr HHV
- Heat Absorbed = 65%
- Cost of Power = \$/Therm / 11.1

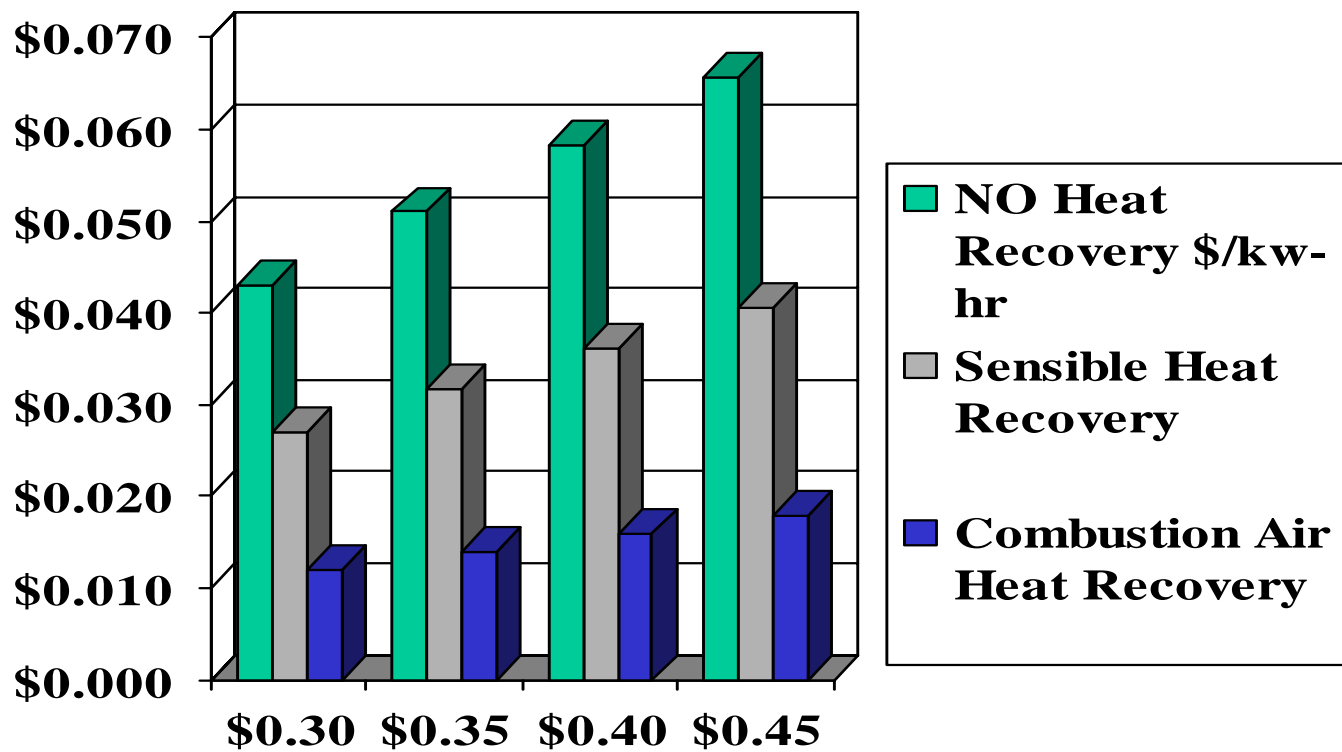


# COMBUSTION AIR HEAT RECOVERY

**4000 Btu/kW-hr HHV; Turbine Exhaust totally displaces Boiler Heat Input.; Cost of Power = \$/Therm / 25**



# COST OF POWER

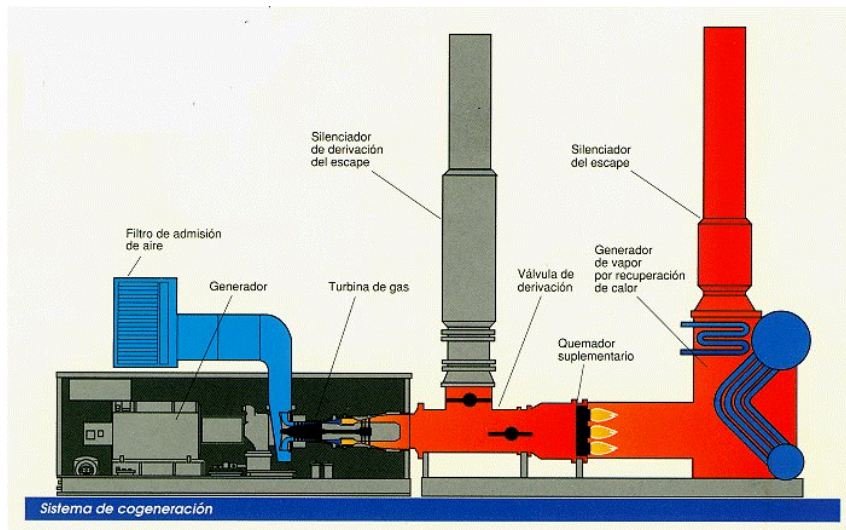


# EFFICIENCY ISSUES

Central Plant	DER - MTG	DER - RICE
Simple Cycle 35%	No heat recovery 23% w/o recup 28% w/recup	No heat recovery 35%
-	Sensible Heat Recovery 38-45%	Sensible heat recovery 40-45%
Combined Cycle 58-60%	Combustion Air Heat Recovery 85%	Combustion Heat Recovery 85%

# EFFICIENT UTILIZATION OF WASTE HEAT LOAD DETERMINES QUALITY DG

# TYPICAL ARRANGEMENT



By installing an HRSG into the exhaust duct of an existing or newly built gas turbine or engine, is possible to produce steam for the plant process. This results in significantly improved total energy plant efficiency.

The steam produced can be used for heating, cooling (with absorption chillers) or additional electric power (with a steam turbine in a Combined Cycle).

Large annual saving in energy bills are possible by installing an integrated CHP (Cogeneration) system if host currently generates own heat but purchases all of its electric generating capacity.

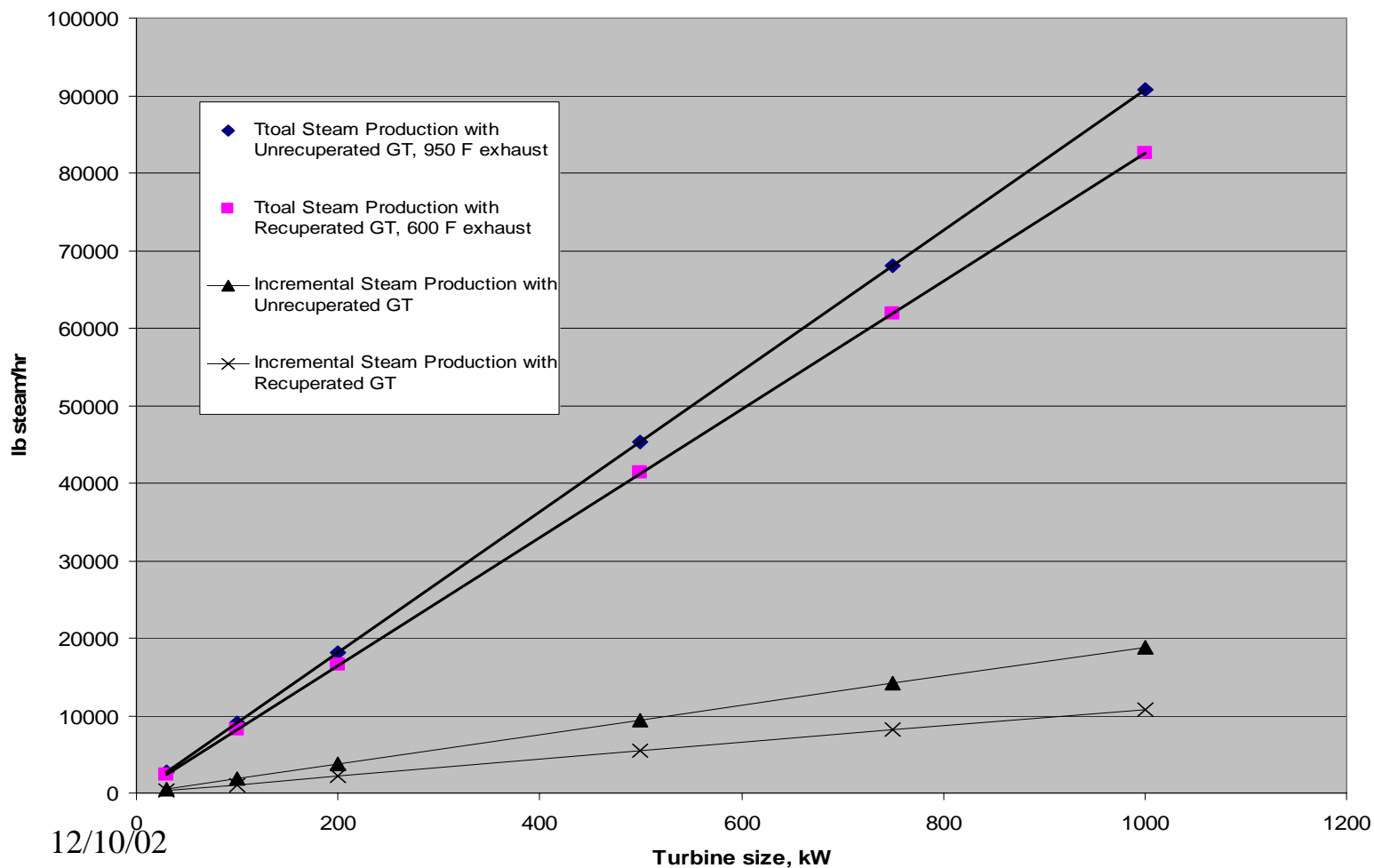


# SYSTEM MATCHING

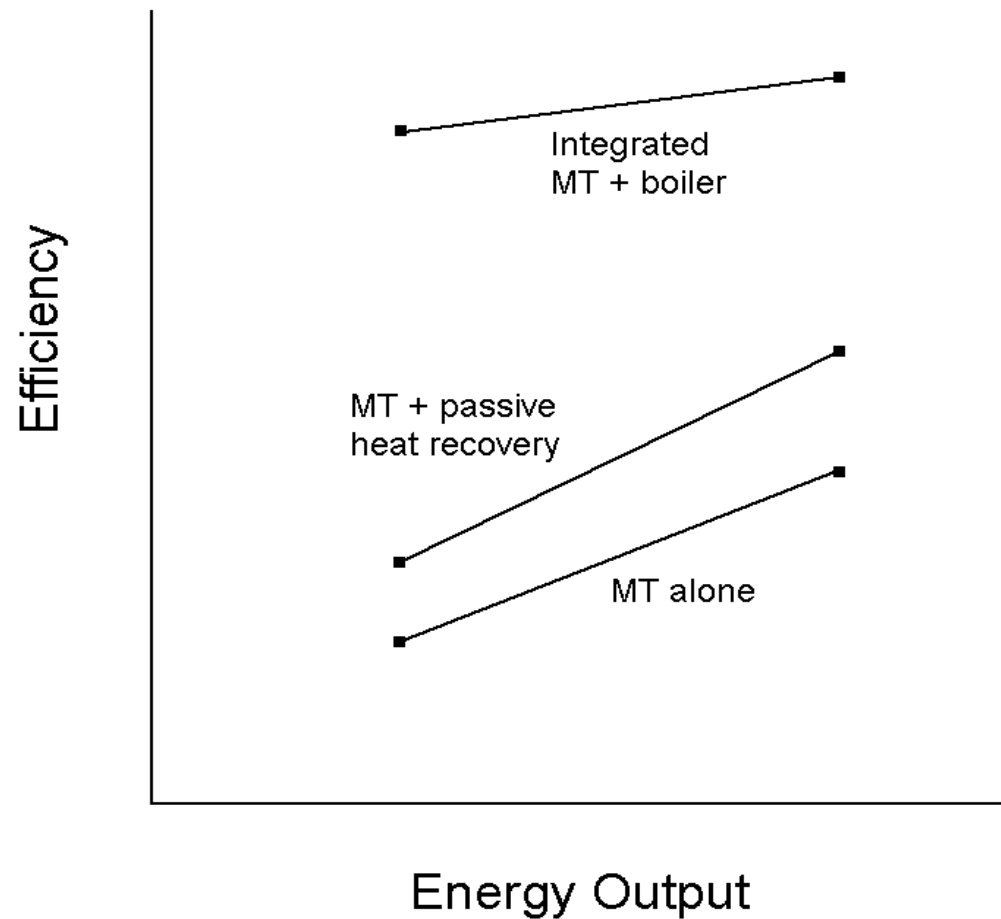
- Match electric generator (MTG) to heat load capacity for optimum economy and performance
  - Host site heat and power loads
  - Load cycles
  - Cost of electricity
  - Cost of heat
  - Fuel displacement
- Combustion air heat recovery implies, as a minimum, all the air from the turbine is used

# MATCHING MTG WITH HEAT LOAD

Steam Production - 160 psia saturated

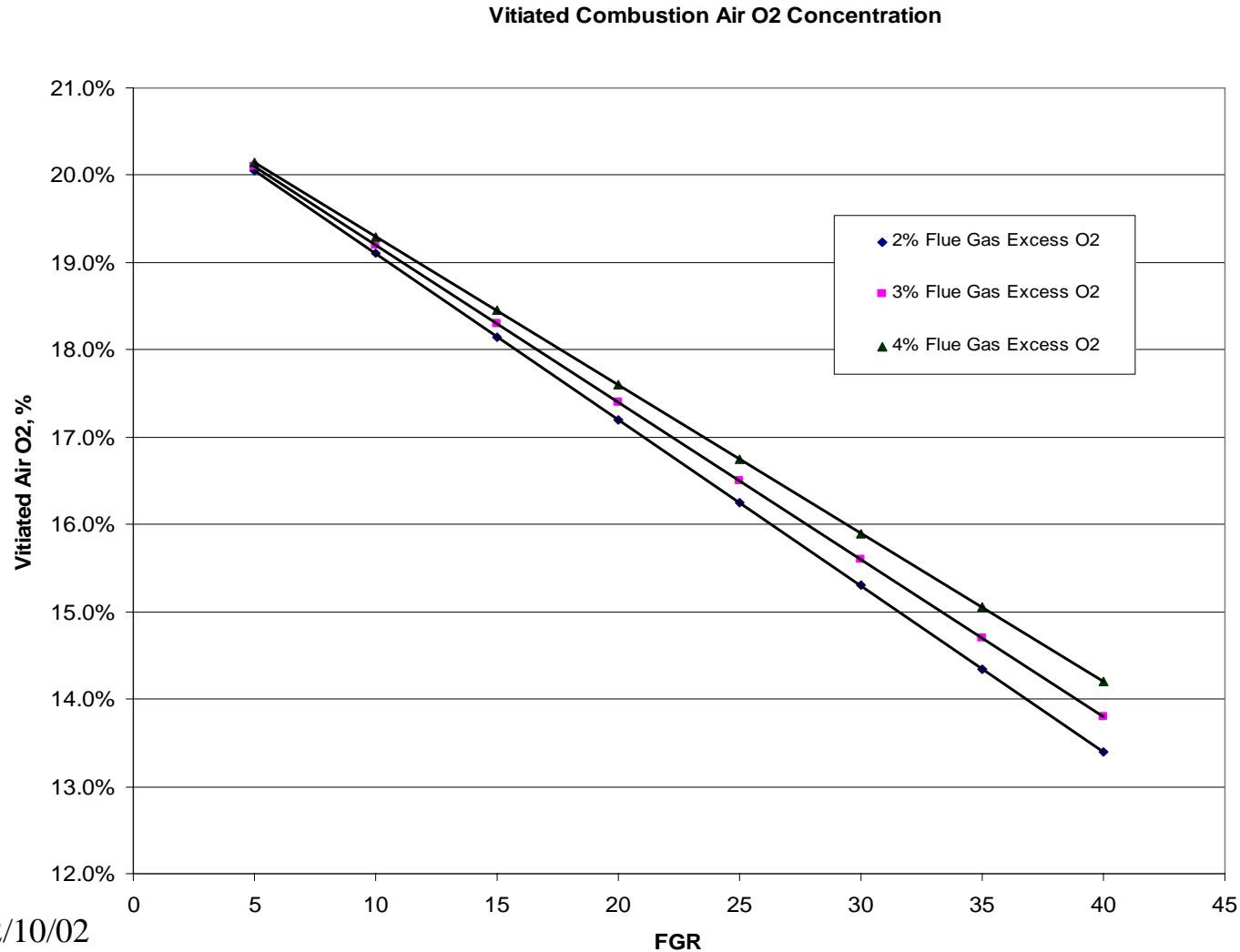


# POWER/HEAT LOAD SCENARIOS

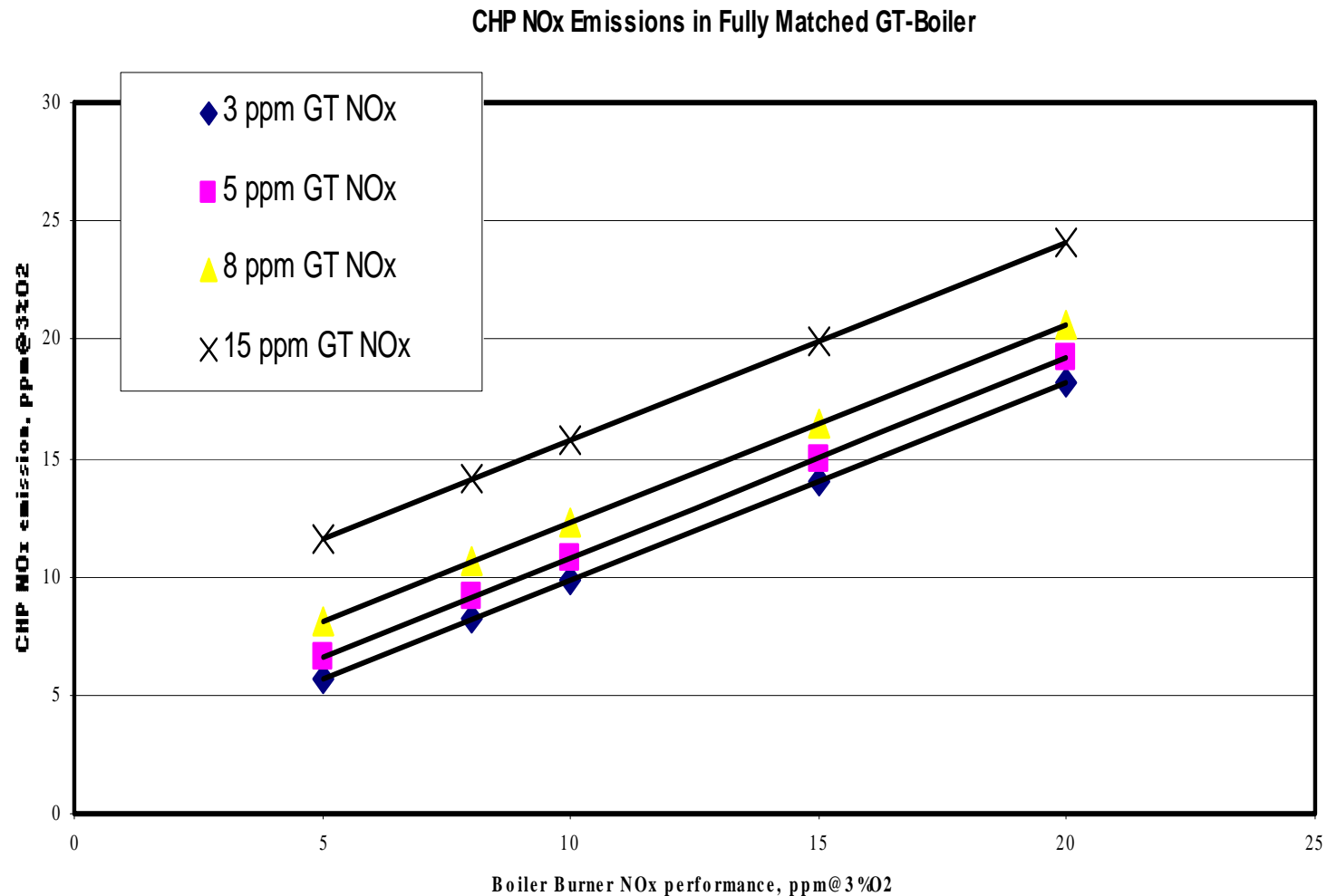


# EMISSIONS ISSUES

# MTG EXHAUST = VITIATED AIR = FGR



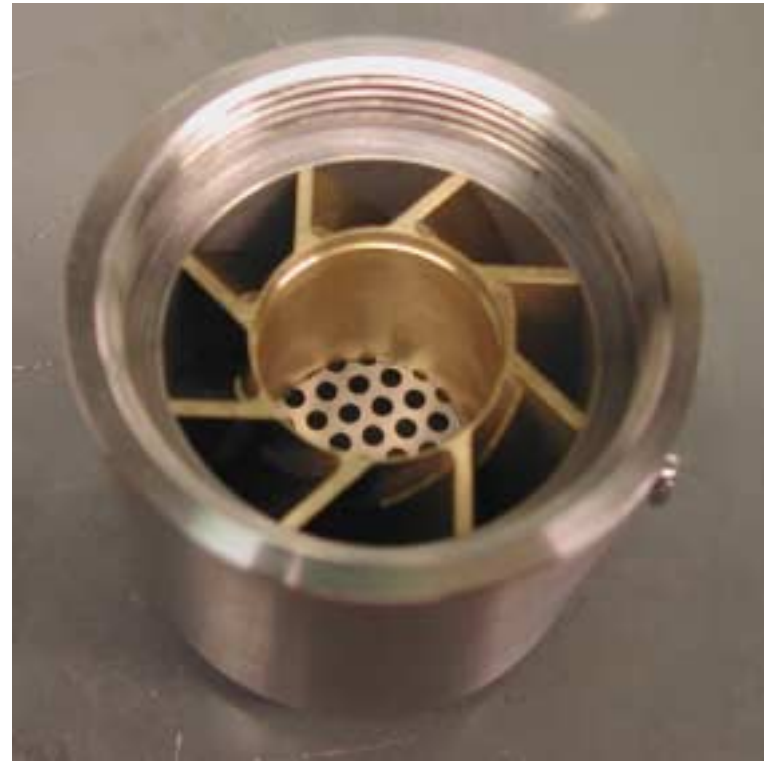
# NEED FOR LOW NOX PERFORMANCE



# DER COMBUSTION ATTRIBUTES

- ULTRA LOW MTG COMBUSTOR
- ULTRA LOW EMISSION BURNER
- LOW EXCESS AIR BURNER
- HIGHLY LOAD FLEXIBLE
- HIGH PREHEAT CAPABILITY
- VARIABLE FGR LEVELS
- LARGE TURNDOWN
- LOW PRESSURE DROP
- EXCELLENT STABILITY, SAFETY AND RELIABILITY
- FUEL FLEXIBILITY
- LOW COST

# LOW SWIRL BURNER RD&D





# LSB APPLICATIONS

- TURBINES AND BOILERS/FURNACES
  - SUB 5 PPM NO<sub>x</sub> EMISSIONS
  - STABLE COMBUSTION
  - 60/1 TURNDOWN CAPABILITY
  - FUEL AND AIR FLEXIBILITY

# Fuel Flexibility

- Natural gas is a desirable fuel because it is hydrogen-rich relative to heavier fuel gases, liquid fuels, and coal (lower CO<sub>2</sub> emissions).
- Combustion-based DER systems need burners that are capable of burning multiple fuels:
  - respond to possible natural gas price excursions
  - energy security - can tolerate interruption of natural gas supply
  - can use alternative fuels
- Need burner designs that are capable of burning a variety of fuels
- Lean premixed combustion offers lowest emissions

# Alternative Fuels

- Biofuels and other renewable fuels can displace consumption of fossil fuels
- Many alternative fuels have lower heat content per unit volume than natural gas (low Btu, or low caloric value fuels)
- Need burners that can burn these fuels cleanly and efficiently
- Adding hydrogen to a fuel can improve its combustion characteristics

# Biofuels and DER

- A significant amount of biomass is converted to carbon dioxide during natural decomposition. If the biomass can be used to generate energy during conversion to carbon dioxide, it displaces use of some fossil fuels.
- Gasification of biomass generally produces a low heat content fuel that may contain significant amounts of hydrogen, carbon monoxide, and water vapor.
- Standard burners for boilers, furnaces, and turbines are generally not well suited to burning low heat content fuels, which are similar to burning natural gas with lots of flue gas recirculation (FGR).
- Use biofuels at their source - transport costs eliminate value

# Hydrogen Production

- **Reforming** is the cheapest way to produce hydrogen, and will continue to be the preferred method for the next few years (at least). Elevated temperatures are needed for reforming reactions to proceed rapidly.
- **Steam Reforming (endothermic):**
  - $\text{CH}_4 + \text{H}_2\text{O} = \text{CO} + 3 \text{H}_2$
  - $\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$
  - net:  $\text{CH}_4 + 2 \text{H}_2\text{O} = \text{CO}_2 + 4 \text{H}_2$
- **Partial Oxidation (exothermic):**
  - $2 \text{CH}_4 + \text{O}_2 = 2 \text{CO} + 4 \text{H}_2$
  - $\text{CH}_4 + \text{O}_2 = \text{CO}_2 + 2 \text{H}_2$
- Hydrogen can be isolated from other gases using a membrane to improve conversion
- Sulfur can poison reforming catalysts; carbon monoxide can poison some fuel cell systems
- Reforming is generally done at  $T > 600^\circ\text{C}$
- Catalysts require periodic replacement
- **Longer term:** bioengineered microbial generation of hydrogen?

# Conclusions

- Efficiency is Important!
- Combustion will continue to be an integral part of DER systems in the foreseeable future
- Well-designed DER systems offer efficiency and emissions that are comparable, or better than, combined-cycle power plants
- Research is needed to develop burners and combustors for systems that are used in DER facilities